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SURFACE QUALITY ANALYSIS OF 102Cr6 BEARING STEEL AFTER CC6050 INSERT BY HARD TURNING AND BY SG GRINDING WHEEL

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Abstract: *This paper deals with analysis of qualitative aspects of machined surface by hard turning with CC6050 cutting ceramics cutting tool and by progressive grinding with SG grinding wheel on the Seeded Gel grain application. The main area of this article is the analysis and also the process influences on surface roughness and Abbott surface profile and microstructure. The applied cutting conditions (parameters) supposed the influence on fatigue strength or wearing resistance, etc. It is possible to appreciate the complex surface topology evaluation in term of various possible aspects. The main problem of surface integrity resides in the possibility of new theories creation in term of new trends of machining technology. It is necessary to advance functionality of part surfaces.*

Key words: *surface quality, hard turning, progressive grinding, cutting ceramics CC6050, SG ("seeded gel") grinding grain, surface roughness.*

1. INTRODUCTION

The patterns of the cutting process and creation of the desired shape and size of the pieces is the very essence of machining process. New stronger materials are used for expanding the number of components requiring high quality surface. They are very hard to be machined, requiring high dimensional and shape accuracy and high surface quality. Parts with better surface quality bear dynamic loads, are wear and corrosion resistant, increase the functional capacity, reliability and durability of complex mechanisms, and thus also the economic benefit of the whole plant and equipment.

The prerequisite of achieving high quality components is the use of hard machining methods (turning), and finishing by fine machining (grinding). The values of the surface quality of machined parts are to be found in their production technology, especially in the cutting operation [6].

The task is to examine the integrity of the surface to create new theories according to current trends in technological practice. Therefore, from the practical conditions of the manufacturing process the following argument can be deduced. The integrity of the surface has a significant impact on the sequence of manufacturing operations of the technological process. In order to successfully address the quality indicators and surface functionality it might be sufficient to know and be able practically to apply the surface integrity patterns. The recent experiments results belonging to several authors have focused on the vibration study during grinding. However, some vibration analyses were only focused on conventional abrasion, by analyzing the acceleration components as well as the associated quality of machined surfaces. It was analyzed the impact of the cutting conditions and machine tool vibration on the quality of the processed surfaces. In this article we focus on the issue of SG vibration in grinding wheels. Therefore, the purpose of the study is to examine the oscillations in advanced applications based on cutting tools seeded gel grain and its effect on surface quality. It is also considered the issue of hard turning with cutting ceramics (Fig 4). All studied parameters are a prerequisite for the effect of fatigue strength, wear resistance, quality, fit, corrosion stability, etc., which are crucial especially in dynamic stressed parts of machinery and equipment subject to wear.

2. METHODOLOGY OF EXPERIMENTS

In experiments the bearing steel 102Cr6 hardened to 62 HRC was used. It has a chemical composition shown in Table 1 and a microstructure, which consists of martensite (Fig. 1). The chemical composition and mechanical properties were measured on a spectrum analyser JrCCD Spectrolab. Table 1 shows the quantities of elements of bearing steel. The measured results allow verification of conformity with standards in the manufacture and also the heat treatment of steel.

When comparing the SG grinding wheels, we consider the following cutting conditions: depth of cut a_p (mm); feed rate v_f (m.min^{-1}); speed n (min^{-1}).

Table 1

Chemical composition of bearing steel 102Cr6

Chemical Composition	(%)							
	C	Mn	Si	Cr	Cu	Ni	P	S
102Cr6	≤ 1.1	≤ 1.2	≤ 0.65	1.30 to 1.65	≤ 0.25	≤ 0.3	max. 0.027	max. 0.03

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Fig. 1. Device for measuring the spectral analysis JrCCD [5].

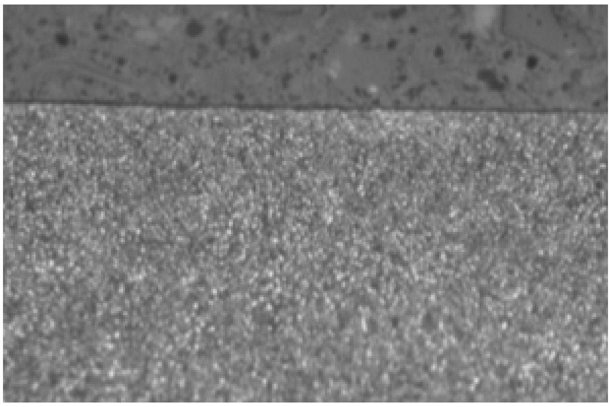

Fig. 2. Microstructure of surface layers of steel 102Cr6 after grinding, etched Nital 3% magnification 500× [2].

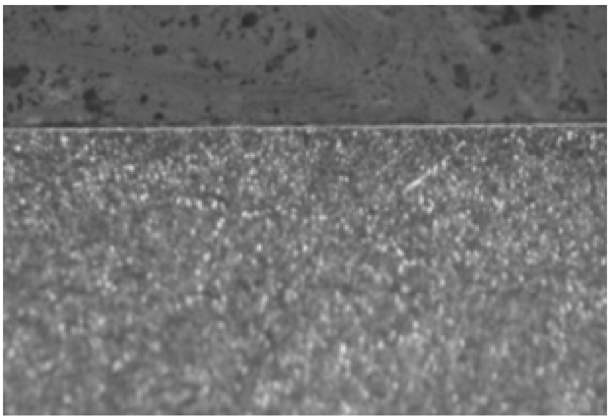

Fig. 3. Microstructure of surface layers of steel 102Cr6 after hard turning dry etched Nital 3% 500× magnification [2].

The cutting fluids used in grinding is EMULZIN H (2% concentration), flow rate 8 l/min. For Al_2O_3 and SG the used parameters were: a_p = 0.02 mm, f_d = 80 μm (Table 2). In hard turning, test samples of CA-ceramics (CC6050) were used for the following cutting parameters: n = 1 600 min^{-1}, a_p = 0.2 mm, f = 0.141 mm, v_c = 142.7 m.min^{-1}.

In Figs. 2 and 3 the microstructure of steel 102Cr6 can be seen. The surface area for hard turning is presented having a continuous layer of residual austenite with a thickness of max. 2 mm (see below annealed globular martensite and carbides). On the surface layer

Table 2

Grinding cutting conditions

Measurement number	a_p **[mm]**	v_f **[m.min^{-1}]**	n **[min^{-1}]**	**Grinding wheel diameter [mm]**
1	0.01	8	2 520	195
2	0.02	8	2 520	195
3	0.03	8	2 520	195
4	0.04	8	2 520	195

after grinding, the incidence of residual austenite layer was observed. The structure presents a well-formed martensite and annealed fine globular carbides.

The experiments follow the cutting force analysis in static and dynamics evaluation terms and also the measurement of surface micro-geometry [2].

2.1. Used for cutting hard material turning – ceramic cutting insert CC6050

There are many uses of ceramic materials, due to higher hardness and wear resistance, being the result of strong ionic or covalent bond. The growing field of application of ceramic materials in machining is due to the increasing replacement of the traditional methods of grinding by cutting operations. Designers constantly require new materials with increased strength and hardness, better thermal properties, and improved wear resistance. But the same required characteristics are met in different appropriate materials. Two examples are hardened steel and alloys, which are characterized by good strength and wear resistance in many applications, maintaining strength at high temperatures of operation. These materials are often used in applications, where a certain degree of precision is required, in which there is at least one machining processes. The technology applied in practice required casting or forging, considering adequate dimensional precision surface quality. As an example, a typical application uses a hardened bearing steel in the automotive industry. Ceramic cutting materials are characterized by high hardness, which is preserved even at high operating temperatures of 1 000 ÷ 300 °C. They are chemically stable and in the cutting process do not react with the workpiece material. Durability of cutting edges of ceramic inserts under correct conditions is very good. Ceramic cutting tools from ceramics (CC "Coromant-Sveden") are use for a large amount of material removed using high cutting speeds [2].

To achieve the machining process quality we need to match the cutting ceramics parameters using available cutting insert with the required physico-mechanical and chemical properties. Among the characteristics influencing the use of CC during operation one includes hardness, tensile strength and bending strength, structure and thermal properties.

Very effective is a homogeneous fine-grain structure of CC, having a very good strength characteristics required for machining technology. Strength property in pressure is comparable with the strength of cemented carbides. However, the bending strength is lower compared with carbides.

Therefore, in CA choice we have to choose the correct geometry of the cutting insert so that in the process

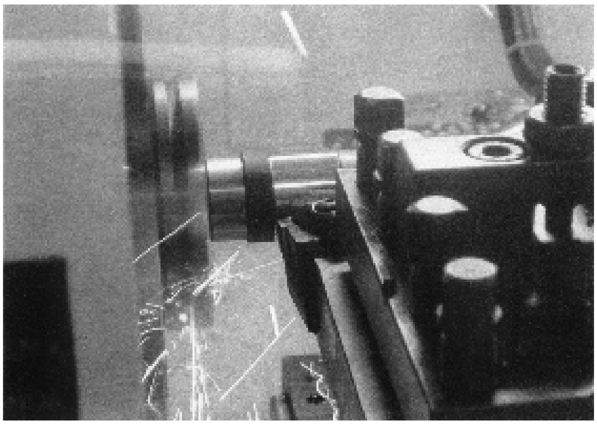

Fig. 4. Hard turning of the test sample of an tool with CA-estate CC6050 on CNC lathe HARRISON Alpha 1300S.

to ensure the rigid ceramic insert mainly the least pressure and bending forces (negative angles γ and λ, negative collar at the forefront of cutting edge).

3. EXPERIMENTAL RESULTS

3.1. Analysis of the relationship between the components of cutting force and the amount of material removed during grinding

Cutting force components were recorded in the computer considering the scheme of experimental measurements. Thus, the obtained records were analyzed obtaining a static view (Fig. 8) as well as dynamic components (Fig. 9). In Figs. 5 and 7 the records of cutting force components compared for grinding wheels are shown. Recording (Fig. 5) shows the components of cutting force after the withdrawal $V_w' = 30$ mm^3 and Al_2O_3 insert after alignment. Shear strength components of worn wheels Al_2O_3, SG after withdrawal $V_w' = 1\,500$ mm^3 are shown in Figs. 5 and 7.

Furthermore, the records are filtered components of the static cutting force and dynamic component, influencing the grinding wheel wear through the static cutting force size for different depths of cut. In particular, the RMS value of cutting force components are much smaller (less dynamic activity) in the applications of this type of abrasive, the grinding wheel maintaining a stable long-term significance of change without cutting action

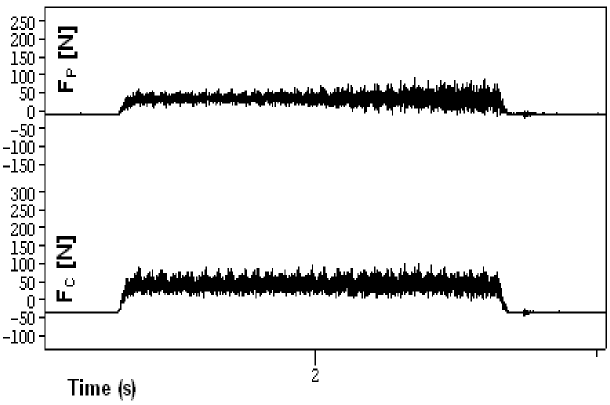

Fig. 5. Signal components of cutting force F_c and F_p for v_w' = mm^3.mm^{-1} in grinding Al2O3 at $a_p = 0.03$ mm, wheel diameter 195 mm [1].

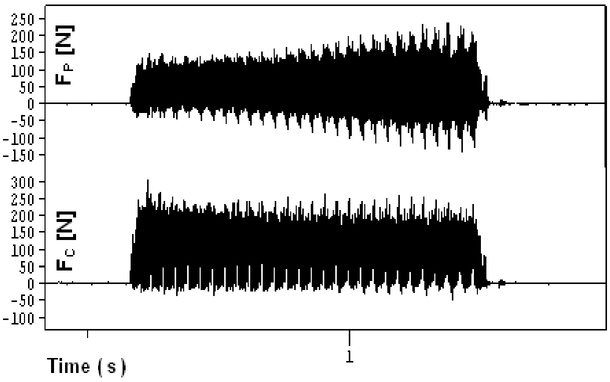

Fig. 6. Signal components of cutting force F_c and F_p for V_w' = 1 500 mm^3 during grinding Al_2O_3 at $a_p = 0.03$ mm, wheel diameter 195 mm [1].

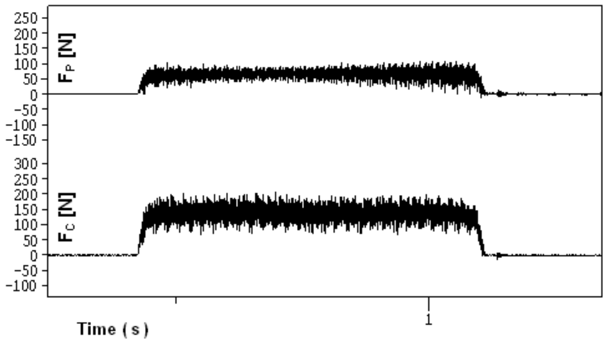

Fig. 7. Signal components of cutting force F_c and F_p for V_w' = 1 500 mm^3 during grinding at $a_p = 0.03$ mm, SG wheel diameter 195 mm [1].

force. These phenomena also confirm the measurements of other authors who have dealt with this issue in the past and show that the size of variation of cutting force components is 2–3 times greater in conventional abrasives compared with the application of SG grains [3 and 4].

The measurement of the static cutting force components showed that differences between the grinding wheels are relatively small especially for small values and so forth.

Also that at higher a_p values the static F_p is for Al_2O_3 less than the in application of SG disc (Fig. 8), again in conjunction with a different mechanism of abrasive wear.

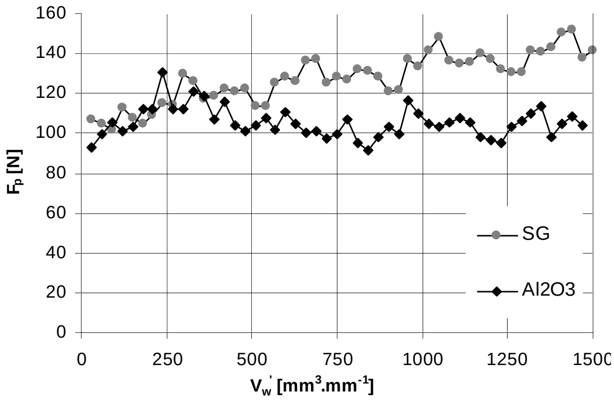

Fig. 8. Influence of V_w' on the static component of force F_p at a_p = 0.03 mm [1].

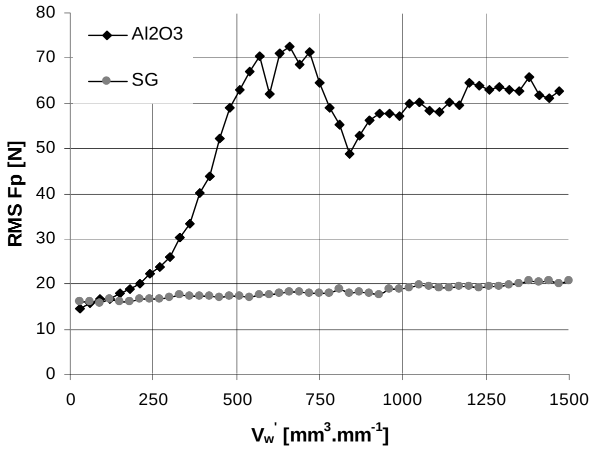

Fig. 9. Influenc of V_w' on RMS F_p values at a_p = 0.03 mm [1].

Analysis of the RMS values of the components has confirmed the fact of previous studies [3, 4], that in the working area of the grinding disc (area where the abrasive grain usually gradually wears) the size of the RMS values of cutting force components significantly changed (only slightly higher values).

In the area where the grinding wheel becomes uninterested, their size is growing rapidly (unlike the static components) and the grinding wheel should be faced.

The results of changes in particular RMS values indicate that the differences in RMS can be seen in relation to long-term interaction with the piece tool which is indicated by the effect of tool wear and is not usually immediately after facing grinding wheel.

3.2. Analysis of the impact of the grinded volume of material to the surface roughness

Another area analyzed the impact of dynamic cutting process and the final shape of the abrasive surface roughness [1].

Roughness of the surface components was evaluated for selected numbers of wheel passes in five places, calculating subsequently the arithmetic average.

Inputs were evaluated in DASYLAB 4.0. Thus, the records were analyzed for various parameters and surface roughness R_a, R_O, R_z. In Figs. 10 and 12 the records of surface roughness after grinding are shown, comparing grinding wheels of Al_2O_3 and SG.

Record of surface roughness on Fig 10 are for the removal V_w' = 30 mm^3 – wheel Al_2O_3 after facing.

Records of surface roughness Al_2O_3 discs, SG after removing material (V_w' = 1 180 mm^3) are shown in Figs. 11 and 12.

In Figs. 10 and 11, it is shown a comparison of the surface roughness for a_p = 0.03 mm and changing the V_w', which is caused by the grinding wheel wear. Figs. 11 and 12 (V_w '= 1 180 mm^3) show that the size of micro-irregularity of the surfaces that were polished by wheels SG is significantly lower than in surfaces polished by Al_2O_3 tool, which is similar in wear and shape.

The comparison between Figs. 10 and 12 shows the surface roughness at a_p = 0.03 mm for changing V_w', which is caused by the grinding wheel wear. For V_w '= 1 180 mm^3 (Figs. 10 and 12) it is shown that the size of surface micro-geometry for polished wheels SG is significantly lower than of the cut surfaces by the Al_2O_3 tool.

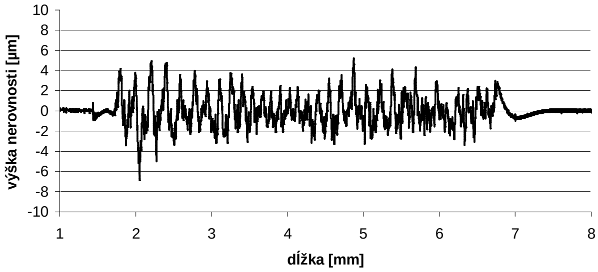

Fig. 10. Record of surface roughness for $V_w{}'$ = 30 mm^3 wheel Al_2O_3 (D = 195mm), at a_p = 0.03 mm [1].

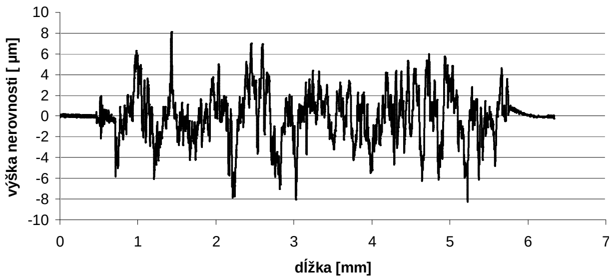

Fig. 11. Record of surface roughness for $V_w{}'$ = 1 180 mm^3 wheel Al_2O_3 (D = 195 mm), at a_p = 0.03 mm [1].

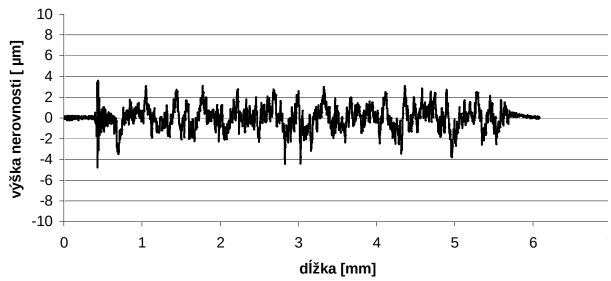

Fig. 12. Record of surface roughness for $V_w{}'$ = 1 180 mm^3 wheel SG (D = 195 mm), at a_p = 0.03 mm [1].

Grinding wheels SG will longer maintain their cutting parameters with respect to their capacity, which is then reflected positively in the surface roughness (Figs. 13 and 14).

An analysis of the impact of the volume of grinded material on the surface roughness shows that with the increase of V_w' the roughness grows. In Figs. 13 and 15 it can be seen the variation of roughness parameters depending on the impact of the grinded material V_w' for each grinding wheel (Al_2O_3, SG).

In Figs. 13–15, a graph of R_a, R_Q, R_z is shown. Two different curve types are represented for the two materials. For the processed surfaces the roughness is comparable (Figs. 13 and 14).

The curves R_a, R_O, R_z in case of SG show less values than in case of Al_2O_3. In the context of increasing RMS, the values of cutting force components as well as the size of R_a increase for conventional disc greater than in case of SG grains [1].

In this area starts grinding wheel wear more and more radius abrasive grains, a grain abrasives, which are beginning to create flat pads and not the cause vibration, but also a larger increase in the cut surface roughness

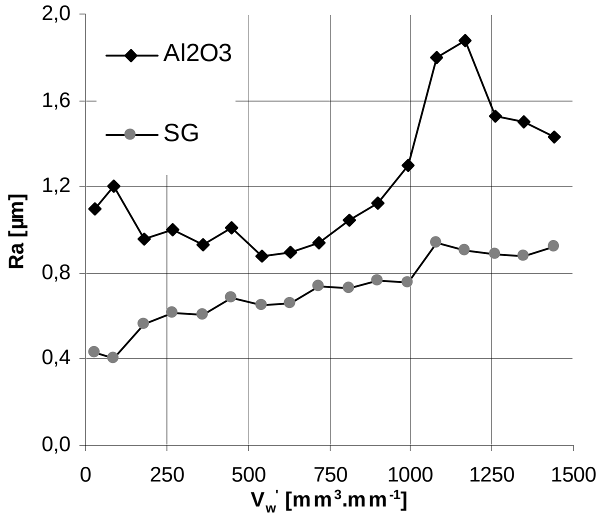

Fig. 13. $V_w^{'}$ ifluence on surface roughness R_a at a_p = 0.03 mm without sparks.

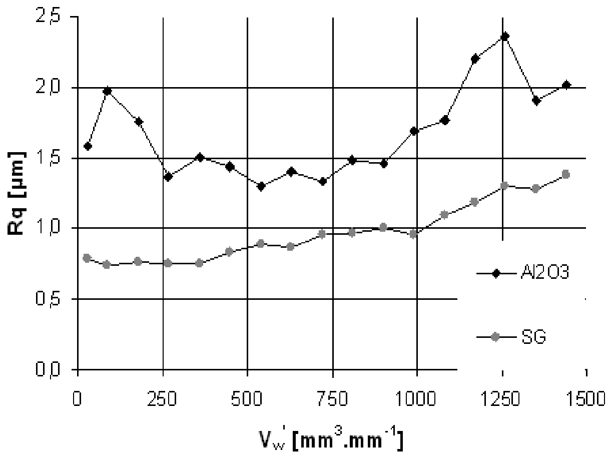

Fig. 14. $V_w^{'}$ influence on surface roughness R_q at a_p = 0.03 mm.

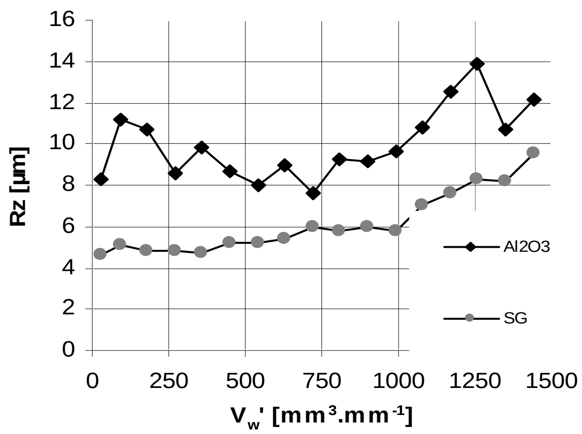

Fig. 15. $V_w^{'}$ influence on surface roughness R_z at a_p = 0.03 mm.

increase in surface roughness in this area also relates to different material removal processes (deformation) in the contact tool and workpiece.

The increase in R_a values as well as some other parameters correlated with the increase in RMS cutting force components values and is therefore heavily influenced by the cutting process dynamics.

3.3. Analysis of the hard turning surface roughness effects

Roughness varies for different machining conditions. Its properties are largely dependent on cutting conditions and geometry.

There are differences in quantitative and qualitative characteristics of roughness of surfaces machined by turning and grinding that are based on different principles, different types of cutting tools as well as the different position of the tool against the workpiece.

The machined surfaces micro-geometry is influenced by several factors. These are the initial conditions (cutting speed, feed motion, and depth of cut), impact on the geometry of the cutting edge (rack angle, clearing angle, and tip radius), influence of the cutting tool material (Ultra Fine – EN, Cutting Ceramics, Cubical Boron Nitride), impact of vibration of the technological system, and not least the impact of cutting tool design.

Cutting parameters for hard turning were chosen to achieve dimensional accuracy, the surface roughness being approximately the same ($R_a \leq 0.4$ µm).

The chosen micro-geometry parameters that are most used in practice (used by 90% of producers) are used to express the value of the roughness R_a and the quality of processed surface.

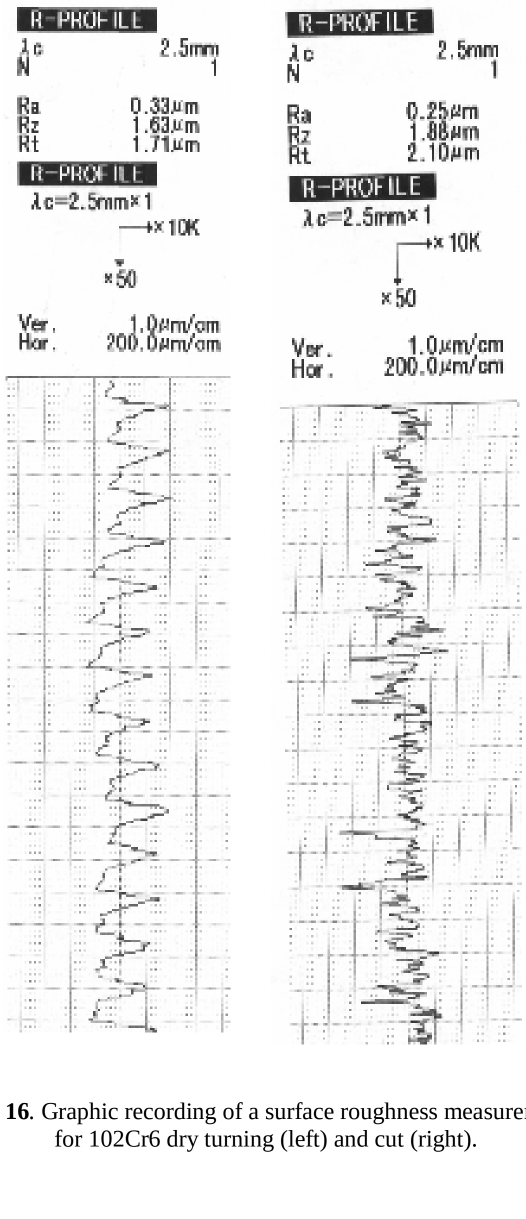

Fig. 16. Graphic recording of a surface roughness measurement for 102Cr6 dry turning (left) and cut (right).

The aim was eliminating the impact of different surface roughness in tribological tests, in which radial wear is higher for surfaces with greater surface roughness.

Verification of the impact displacement (*f*) and cutting speed (v_c) in hard turning is achieved for $f = 0.1$ mm obtaining surface roughness $R_a = 0.20$ mm.

It was changed the feed $f = 0.15$ mm, $r_\varepsilon = 0.8$ mm, $v_c = 150$ m.min^{-1}, $p = 0.2$ mm. It was achieved $R_a = 0.33 \div 0.38$ mm.

Test results of machining various hardened steels confirm that the surface roughness in hard turning is equal to or better than the grinding without sparks (see Fig. 16).

Turning with cooling in many cases even improves the surface roughness.

In addition, the arithmetic average roughness R_a is different for a better measured surface and an assessed material profile (Abbott curve), as the surface roughness is only slightly indicative of the functional properties of the machined surface.

9. CONCLUSIONS

The paper assessed the state of the surface layer of specimens of 102Cr6 hardened steel (HRC = 60 ± 2) by measuring the microgeometry (surface roughness and Abbott curve), and microhardness during hardening, and also metallographic evaluation of the surface layer structure called white layer.

The microstructure of individual samples for all the hardened material shows a continuous white surface layer thickness from 0.002 to 0.004 μm for hard turning of all hardened steels. This white layer is absent or very thin and interrupted in grinding.

Cutting parameters for hard turning and grinding were chosen in order to achieve the same dimensional accuracy. The surface roughness for both processes was approximately the same ($R_a \leq 0.4$ mm).

The standard parameters that are most used in practice (used by 90% of producers) are used to express the value of the roughness R_a and the quality of processed surface.

Test results of machining various hardened steels confirm that the surface roughness in hard turning is equal to or better than the grinding. Turning with cooling in many cases even improves the surface roughness.

The results of extensive testing on the next types of high strength steels are as follows:

- microgeometry in hard turned (dry or with cooling) is equal to or better than in plunge grinding,
- surface roughness and material share at 40% distance from the surface of irregularities show that is better to cut surfaces comparing 58 ÷ 60 ÷ 38% versus 40% for turning,
- grinding of hardened steels arises from strong tempered HV0, *1* = up to 900 HV0, *1* = 700 ÷ 750 with impaired crystal surface.

Assignments scientific contribution is that it broadens the knowledge of hard turning dry cooling is a wider range of machining of hardened steel, but mostly extends knowledge of the integrity of the machined surfaces and hardened steel used in automotive industry [6].

This opens the way for further research in this field, for optimizing machining processes of hardened components in the manufacture of their dominant function surfaces. It can reasonably be assumed that the development of methods and direct monitoring means, and modeling of functional surfaces in hardened steel, will further increase the operational reliability and durability of machine parts and equipment. As further research it is necessary to observe and change the character and behavior of the machined surfaces and verify the impact of turning CBN on the integrity of the surface of hardened steels.

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